Tropical Observability and Predictibility

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LONG-TERM GOALS

A long-term goal of this research is to improve dynamical prediction of tropical cyclones using ensemble methods for making analyses and forecasts. A second goal is to use the information contained in ensemble analyses and forecasts to improve basic understanding of tropical cyclone dynamics. Finally, a third goal is to use ensemble-based sensitivity analysis to target observations for tropical cyclone predictability and to assess the impact of observations on tropical cyclone forecasts.

OBJECTIVES

Specific objectives organize around the challenge of informing dynamical forecasts with observational information in tropical cyclone environments. Since these environments are atypical, traditional methods for constructing analyses from observations do not perform well. Ensemble methods naturally account for these atypical environments, and offer the opportunity for a leap forward in tropical cyclone forecast skill. Our main objective is to explore the utility of ensemble Kalman filters for creating analyses and forecasts of tropical cyclones, including genesis, intensity change, and extratropical transition.

APPROACH

The technical approach has involved adapting an ensemble Kalman filter (EnKF) for use in tropical environments. Early work on the project, in collaboration with Jim Hansen (NRL), was aimed at making accurate analyses of tropical environments in which tropical cyclones form, using idealized simulations of radiative-convective equilibrium to create idealized atmospheric profiles for assimilation. Dr. Ryan Torn, former graduate student at the University of Washington and currently an Assistant Professor at the University at Albany (SUNY), conducted this research.

Having developed experience with tropical assimilation, an opportunity to apply the technique arose in 2005 with the success of the RAINEX field project. Dr. Torn and the PI conducted experiments assimilating conventional observations and aircraft deployed dropsondes for hurricane Katrina (2005). Dr. Torn also applied the technique to the problem of extratropical transition over the western North

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14. ABSTRACT
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15. SUBJECT TERMS

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Pacific Ocean, and was involved in the development of a new technique for quantifying forecast sensitivity and targeting observations.

The project was re-scoped to focus on the Tropical Cyclone Structure project (TCS08). University of Washington graduate student Rahul Mahajan created an operational, real-time, EnKF for use during the field phase of TCS08. This system produced analyses every 6 hours and forecasts to 72 hours twice daily. Sensitivity calculations based on the ensemble data were used to help target aircraft deployment during the field campaign.

WORK COMPLETED

The EnKF has been successfully deployed for hurricane Katrina (2005). A nested domain, with a 30 km outer domain and 10 km inner domain, was deployed for a 90-member ensemble. For the control case, only conventional observations were assimilated, including Automated Surface Observing System (ASOS) surface stations, ships, buoys, radiosondes, cloud-track winds, and Aircraft Communications Addressing and Reporting System (ACARS) observations. A test case assimilates aircraft-deploy dropsondes in addition to all observations for the control case. Ensemble forecasts were produced from the ensemble analyses for both the control and test cases, and the errors in tropical cyclone (TC) track and position compared to other operational forecasts.

The EnKF has also been successfully deployed to the problem of extratropical transition over the western North Pacific Ocean. Two cases have been considered in detail: Typhoons Typhoons Tokage (2004) and Nabi (2005). These cases were chosen because Tokage was characterized by large forecast errors, whereas Nabi had relatively small forecast errors. Experiments for both cases consisted of cycling an EnKF on conventional observations for the time period surrounding extratropical transition. Ensemble sensitivity analysis was then used to evaluate the relationship between forecast errors and initial condition errors at the onset of transition, and to objectively determine the observations with the largest impact on forecasts of these storms.

Preliminary work has proceeded on typhoon Nuri (2008), which was sampled during TCS08. Our current emphasis is on the time period during genesis. A control EnKF ensemble set of analyses has been produced on 27 km and 9 km grids by assimilating conventional observations. While we wait for field observations to be released, we are currently working on using sensitivity analysis on the genesis period, with a particular emphasis on sensitivity of genesis to low- and mid-tropospheric moisture.

A new ensemble-based sensitivity technique, used in the research described above, was developed by the PI in collaboration with Drs. Ryan Torn and Brian Ancell (University of Washington). Typically, sensitivity analysis involves an adjoint model run deterministically backward in time. Our novel innovation is to use ensembles of independent samples of analyses and forecasts to determine sensitivity statistically. The PI and collaborators have defined the mathematical basis for ensemble sensitivity, including the relationship to adjoint sensitivity and targeting observations.

RESULTS

For the assimilation research project on hurricane Katrina (2005), Torn and Hakim (2008) find that observation assimilation consistently reduces errors in tropical cyclone position, but not necessarily in intensity. However, withholding observations leads to significantly larger errors in both quantities. Analysis increments for observations near the tropical cyclone are dominated by changes in vortex position, and these increments increase the asymmetric structure of the storm. Data denial experiments indicate that dropsondes that sample the synoptic environment provide minimal benefit to the outer domain; however, dropsondes deployed within the TC lead to significant reductions to the position and intensity errors on the inner domain. Specifically, errors in the inner domain ensemble-mean six-hour forecasts of minimum pressure are 70% larger when dropsonde data is not assimilated. Precipitation fields are qualitatively similar to TRMM satellite estimates, although model values are generally higher. Moreover, the ``spin up'' period and initial imbalance in EnKF-initialized WRF forecasts is less than starting the model from a GFS analysis. Ensemble 48-hour forecasts initialized with EnKF analyses have track and intensity errors that are 50% smaller than GFS and NHC official forecasts. In particular, the observed southwesterly track across Florida, which was missed by all operational forecasts, is captured by the EnKF (Figure 1).

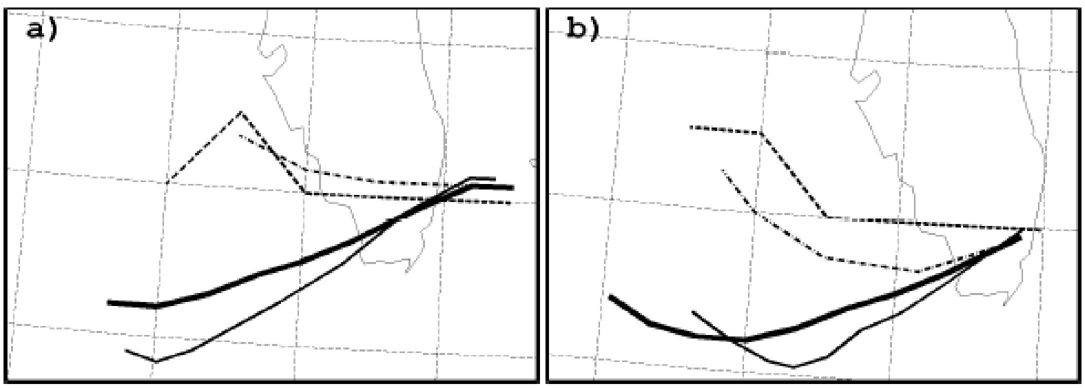

Figure 1. 48-hour forecasts of Katrina's track for the WRF-EnKF ensemble-mean (thick solid line), GFS (dashed line), official NHC forecast (dashed-dot line), and best-track (thin solid line) initialized at (a) 1200 UTC 25 August 2005, and (b) 0000 UTC 26 August 2005. Latitude and Longitude lines are shown every 2 degrees.

For the extratropical transition research project, Torn and Hakim (2009, in preparation) find that for both cases (Tokage and Nabi), 48-hour cyclone minimum sea-level pressure forecasts and the RMS error in sea-level pressure are most sensitive to the TC position and to mid-latitude troughs that interact with the tropical cyclone during transition (Figure 2). Diagnostic perturbations added to the initial conditions based on ensemble sensitivity reduce the error in both the minimum sea-level pressure forecast and sea-level pressure field near the TC by 50%. Observation impact calculations indicate that assimilating approximately 40 observations in regions of initial-condition sensitivity produce a large, statistically significant impact on the 48-hour cyclone minimum sea-level pressure forecast. For the Tokage forecast, assimilating the single highest impact observation, an upper-tropospheric zonal wind observation from a Mongolian rawinsonde in a highly sensitive region, yields 48-hour forecast perturbations in excess of 10 hPa and 60 m in sea-level pressure and 500 hPa height, respectively (Figure 3).

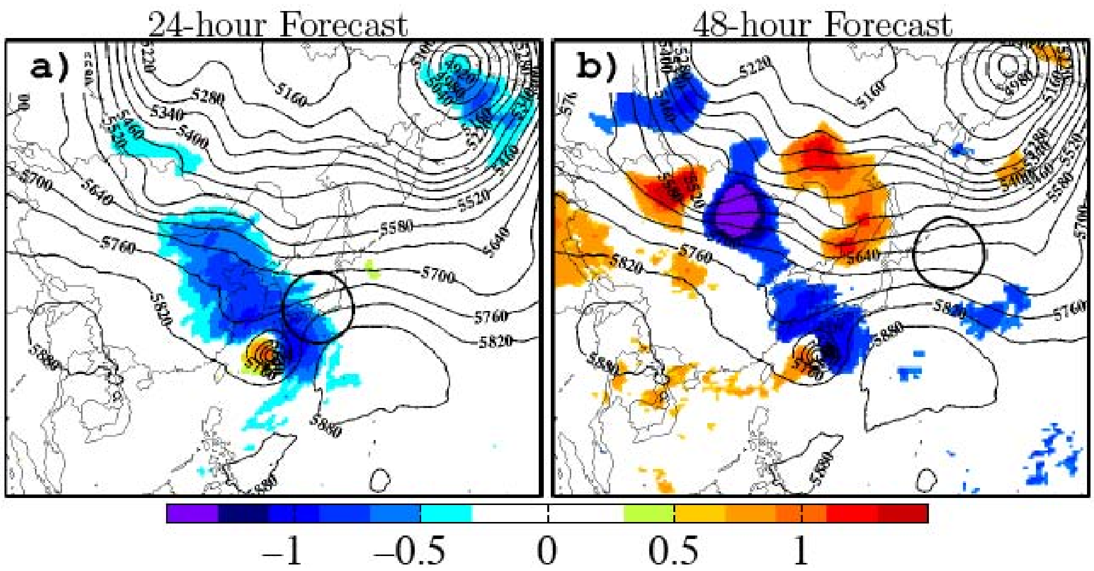

Figure 2. Sensitivity of (a) 24 hour and (b) 48 hour forecast errors within the bold circles to 500 hPa height initial-condition perturbations at 1200 UTC 19 October 2004 (Tokage). Contours give the analyzed 500 hPa height field and colors give the sensitivity of the mean-sea-level pressure forecast errors to a one standard deviation perturbation in the 500 hPa analyzed height field. For the 24 hour forecast, sensitivity is largest near the tropical cyclone, whereas the 48 hour forecast is more sensitive to errors near upstream troughs.

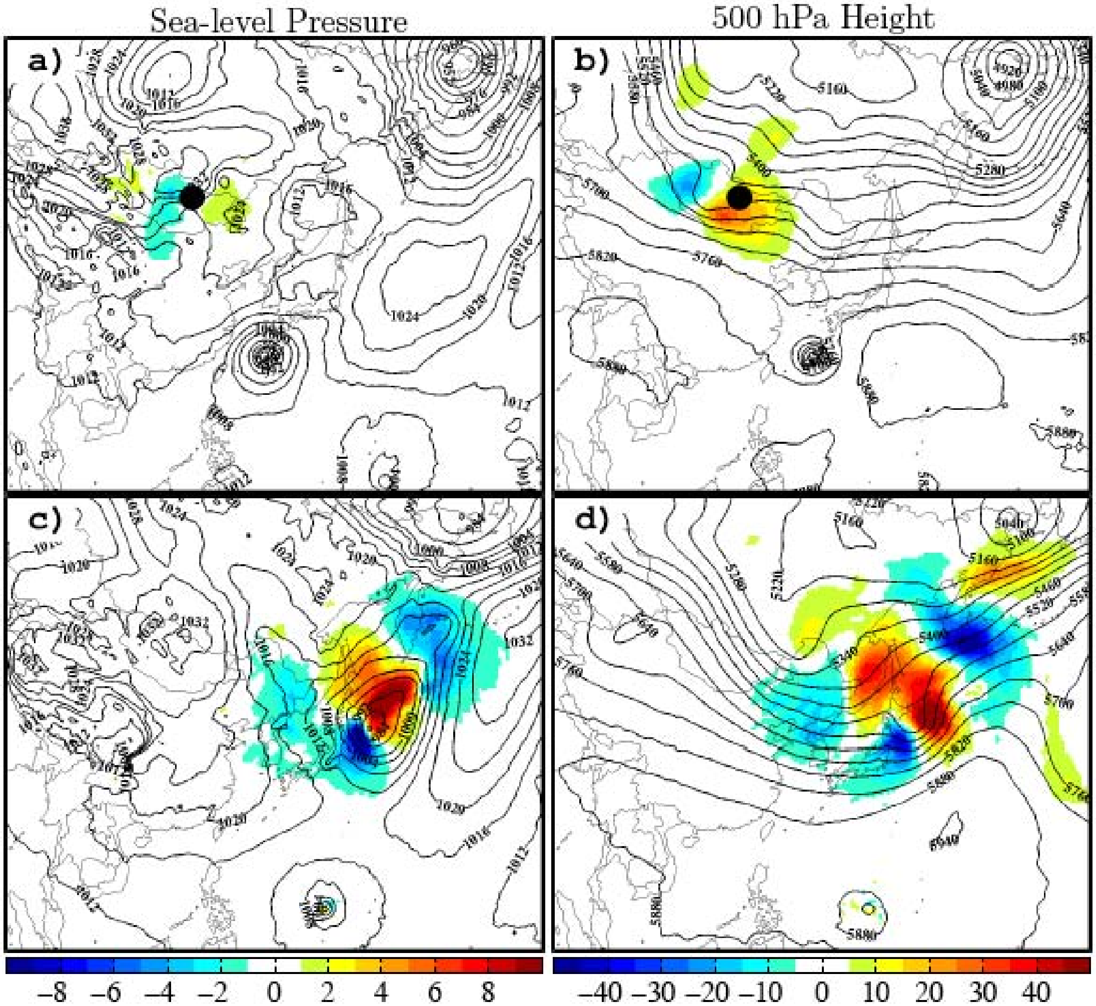

Figure 3. Impact of assimilating a single Mongolian radiosonde 250 hPa zonal wind observation (black dot). Control fields are shown in contours, and perturbations in colors. (a) mean-sea-level pressure at 1200 UTC 19 October 2004. (b) as in (a), but for the 500 hPa height field. (c) and (d), as in (a) and (b) but for the 48-hour forecast.

IMPACT/APPLICATIONS

Improvements to forecasts of tropical cyclone structure, intensity change, and extratropical transition require improvements in the initial specification of the vortex. The research in this project provides proof of concept for: (1) more-accurate vortex specification in the initial condition, (2) much reduced forecast errors for both track and intensity, and (3) targeting observations near tropical cyclones and identifying high-impact observations. As a result, the impact of this research may be considerable if deployed in operational systems.

RELATED PROJECTS

Dynamics and Predictability of Tropical Cyclone Genesis; ONR Grant Number: N00014-09-1-0436.

PUBLICATIONS

Huntley, H. S., and G. J. Hakim, 2009: Assimilation of time-averaged observations in a quasi-geostrophic atmospheric jet model. Climate Dyn., 32. [submitted]

Torn, R. D., and G. J. Hakim, 2009: Initial condition sensitivity of western-Pacific extratropical transitions determined using ensemble-based sensitivity analysis. Mon. Wea. Rev., 137. [in press, refereed]

Torn, R. D., and G. J. Hakim, 2009: Ensemble Data Assimilation applied to RAINEX observations of Hurricane Katrina (2005). Mon. Wea. Rev., 137, 2817—2829. [published, refereed]

Torn, R. D., and G. J. Hakim, 2008: Performance characteristics of a pseudo-operational ensemble Kalman filter. Mon. Wea. Rev., 136, 3947-3963 [published, refereed]

Torn, R. D., and G. J. Hakim, 2008: Ensemble-based sensitivity analysis. Mon. Wea. Rev., 136, 663-677. [published, refereed]